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X. *An Account of some Appearances attending the Conversion of cast into malleable Iron. In a Letter from Thomas Beddoes, M. D. to Sir Joseph Banks, Bart. P. R. S.*

Read March 24, 1791.

S I R,

YOU are undoubtedly well apprized of an alteration lately introduced into our manufactories of iron, in consequence of which the reverberatory has been substituted in the place of the finery furnace. The new process is capable of being indefinitely varied. I have lately been favoured with an opportunity of observing one of these variations with every advantage I could desire. As in this method the changes undergone by the metal during the first series of operations lie perfectly open to inspection, a short description of them may not perhaps be unworthy the notice of philosophical chemists. Allow me to premise further, that I did not content myself with a single examination; and, for the sake of greater accuracy, I took minutes of the phenomena, and of the time when they occurred. A very intelligent workman was at the same time directed to answer all my questions, so that I enjoyed the benefit of his experience also.

In somewhat more than half an hour after it was put in, the charge consisting of $2\frac{1}{2}$ cwt. of grey pig iron was nearly melted. The workman now began to stir the liquid mass:
for

for this purpose he used sometimes an iron lever, and sometimes a kind of hoe; but he first turned the flame from off the metal, which is done by letting down a damper upon the chimney corresponding to that with which ordinary reverberatory furnaces are provided, and by raising the damper of a second chimney, which proceeds immediately from the fire-place, and carries off the flame, current of air, &c. without allowing it pass into the body of the furnace.

In 50 minutes from the commencement of the operation, the metal had become in consequence of the constant stirring loose and incoherent; it appeared about as small as gravel; it was now also stiff, and much cooled.

55 m. from the same period, flame turned on again. Workman keeps stirring and turning over the metal; in 3 m. it becomes soft and semi-fluid; flame turned off; the hottest part of the mass begins to heave and swell, emitting a deep blue lambent flame. The workman calls this appearance fermentation.

1 hour 1 m. blue flame breaking out over the whole mass; heaving motion also general.

1 h. 13 m. metal full as hot, or, as the workman and myself both judged, rather hotter than at the instant the flame was turned off, though it is now a quarter of an hour since.

1 h. 18 m. where there is no heaving and no blue flame the mass is sensibly cooler, and only of a dull red heat.

1 h. 20 m. workman observes, that the metal sticks less to his tools. Pig-iron, he says, fastens upon it immediately, and must be shaken off by striking the other end with a hammer; as it approaches more and more towards *nature* (malleable iron) it adheres less; and when the tools come clear up out of the mass, he judges it to be fermented enough.

1 h. 23 m. little heaving or blue flame; metal stiffer, and of a dull red; flame turned on and soon off again.

1 h. 26 m. by constant stirring the metal is become as fine as sand. Workman remarks, that the flame, which reappears over the whole mass, looks more kindly. It is evidently of a lighter blue colour.

1½ h. flame turned on and soon off again. Mass ferments strongly. Hissing noise heard: this noise was distinguishable in some degree ever since the blue flame and heaving motion became visible, but always faint till now.

1 h. 40 m. less blue flame.

1 h. 48 m. flame twice turned on and off in this interval. Metal now clots, stands wherever it is placed, without any tendency to flow, and no liquid pig iron now remains in the basin of the furnace; the mass has been constantly stirred and turned over.

1 h. 50 m. a little finery cinder appears boiling up amid the mass. Workman attributes the increase of the hissing to this.

1 h. 53 m. scarce any perceptible blue flame or heaving. All the metal is now gathered into lumps, which the workman beats and presses with an heavy-headed tool. He brings them successively into the hottest part of the furnace, into which the flame has been admitted. He now stops the port hole in the door at which he had introduced his tools, and applies a fierce flame for 6 or 8 minutes; the metal is then rolled.

These appearances, at least the most interesting of them, seem to admit of an easy explanation; and I offer the following observations as supplemental to those for which we are already indebted to the Swedish and French chemists on this important branch of metallurgy. I assume the following propositions as already proved by these philosophers. 1. That cast iron

iron is iron imperfectly reduced, or, in other words, that it contains a portion of the basis of vital air, the oxygène of M. LAVOISIER. 2. That it contains a portion of plumbago, with which grey cast iron most abounds. 3. That plumbago consists of iron united to charcoal. 4. That fixed air, which I would rather call carbonic acid air, consists of oxygène and the constituent parts of charcoal.

The heaving or swelling motion, so conspicuous in the process, is doubtless owing to the discharge of an elastic fluid; and the lambent deep blue flame, breaking out in spots over the whole surface, shews, that this elastic fluid is an inflammable gas of the heavy kind. That no doubt might be left upon the former of these circumstances, I directed the workman to take out, at two different periods, a quantity of the metal where it was working most strongly. Both proved, on examination, to be spungy, cellular, and full of bladder holes.

The heavy inflammable air, I imagine, is produced in this manner. The oxygène of the imperfectly reduced metal combines with the charcoal to form fixed air; at the same time another portion of charcoal is thrown into an elastic state, that is, into inflammable air, and burns on the surface with a very deep blue flame, on account of the admixture of fixed air. The heat which is so obviously generated in the mass at the beginning of the fermentation, I attribute to the combination of the oxygène and charcoal; a fact which, with several others as I have already remarked on another occasion *, shews, if not the falsehood, at least the imperfection of the modern doctrine on the subject of heat. The acidifying principle, it would appear, has some power of generating heat independant of its condensation. Here abundance of elastic matter is

* Chemical opinions of a philosopher of the last century.

discharged; yet, notwithstanding the heat absorbed by its formation, and that which flows out of the metal in all directions, the whole mass becomes hotter. The oxygen cannot be supposed to have much specific or latent heat, because it undoubtedly exists in the iron in a very condensed state. Neither does the appearance of the mass allow me to ascribe this generation of heat to the burning of the inflammable air at the surface, as will also be immediately evident for another reason. The less deep blue colour of the flame at a subsequent period in the operation is probably owing to the absence of fixed air, or at least to its being produced more sparingly, the oxygen being now nearly consumed. It will not appear surprising, that the oxygen in this case should be consumed before the charcoal, if it be considered, 1. that grey iron contains a large portion of plumbago; and, 2. that fixed air contains a much larger quantity of oxygen than of charcoal; near three times as much, according to our best experiments on its formation: so that I ascribe the subsequent fermentation accompanied with the lighter coloured flame almost entirely to the conversion of the charcoal into an elastic fluid. A very experienced philosopher, I am well aware, has asserted, that water is necessary to this conversion; an opinion concerning the justness of which I have long entertained great doubts. Whenever I have distilled charcoal *per se*, I have found the first portions of gas to contain fixed air; an appearance owing, as I believe, to the decomposition of water absorbed from the atmosphere; but, after continuing the process for some time, there has still been a production of inflammable air; but from this neither lime-water nor milk of lime would absorb any portion, though when fired with vital or common air, it would produce fixed air; and if moisture was added to the charcoal, inflammable

and fixed air would be generated anew. Moreover it appears, from the experiments of Dr. AUSTIN and some others, that charcoal consists of the hydrogène and azote of the French chemists. How far it may be difficult or impossible entirely to convert charcoal in its ordinary state into gas, is a point I wish to see more fully illustrated by future experiments. At present it seems obvious, that the circumstances of the operation I have described are particularly favourable to this conversion: for, 1. not to mention the violence of the heat, we have this substance in a very attenuated state, so that, very probably, the expansive power of fire is very little, if at all, counteracted by the attraction of cohesion, which cannot be said in the case of the most minute mechanical division we can effect. 2. The attraction of the particles of the iron for one another will produce an effort to extrude the intermixed particles of charcoal, and thus enable it more readily to assume the elastic form.

Now, during the continuance of the lighter coloured blue flame, the mass, as I observed, shews no power of generating heat within itself; a circumstance which indicates that the heat produced in the former part of the operation does not depend on the burning of the gas at the surface; and I think inspection will satisfy any one that it is produced in the heart of the mass. It may indeed be objected, that the metal, now brought nearer to the state of malleable iron, may require a greater supply of heat to keep it at the same temperature. It is less fusible, as we are well assured. By referring back to the minutes you will observe, how very often it was necessary to turn the flame upon the mass during this second fermentation in order to keep it in a state in which it could be worked.

The very copious production of elastic fluids during an hour, and often during a much longer space, for in this instance the

process was remarkably successful and short, does not seem favourable to a late ingenious hypothesis, according to which water is the embodying principle of all elastic fluids. I have never indeed considered this as very probable, and, after the observations I have related, I see no means of defending it. Will it be said, that the pig iron, as being in some sort a calx of iron, contains water?

In annealing crude iron, with or without charcoal, it is well known to increase in all its dimensions. I have seen bars originally straight bent like an S, when long exposed to heat in circumstances where they could not extend themselves endways. I suppose this phenomenon may be owing to a very small beginning of this fermentative motion, which acts as an internal principle of expansion. Cast iron bars, not in contact with charcoal, would, according to this supposition, by long annealing lose of their weight; or if the heat was too low for the elastic fluid to be discharged from their substance, they would probably blister like steel: an appearance undoubtedly owing to the generation of air. Mr. HORNE, in his Essay on Iron, somewhere remarks, that on opening these blisters he has heard a whistling noise as of air rushing out.

During the whole of this process, frequent jets of white sparks, of a dazzling brightness, played from the surface of the metal. They would have afforded an extremely beautiful spectacle but for the inconvenience of looking on so hot a mass. They arose, no doubt, from the burning of small portions of iron.

The effect of so much stirring as I have noted down does not require to be explained.

The workman was clearly of opinion, that the fermentation of hard or white crude iron is less than of grey in this

process; a fact which perfectly coincides with the preceding observations, since that species contains less plumbago, or in other words less matter fit to produce elastic fluids.

In order to prove the extrication of fixed air during the fermentation of the metal, I once thought of introducing lime-water in an iron vessel within the body of the furnace; but when I considered that the fire-place was not divided by any partition from the body of the furnace, and that the whole building was full of burned air, I omitted the experiment from a persuasion that, even if the lime-water should become turbid, the fixed air might come from another source.

I was not unmindful of the sulphur which exists, as I have reason to believe, in every form of iron manufactured with coaks. I cannot, however, ascribe any of the effects I observed to its presence. There can be little doubt, that some portion was perpetually extricated with the inflammable air during the whole process; for on dissolving pieces of the stamped, or rather the rolled iron in weak muriatic acid, silver held in the extricated air was tarnished as much and as soon as by air from specimens taken out of the furnace at different times during the process. I could not but conclude, that the tarnishing matter came from the iron, when I found the air from a solution of zinc in the same acid, incapable of producing the colour upon silver. The appearance, the want of a martial astringent taste, and the dissolving action of caustic alkali, led me to conclude, that the colour in each experiment with iron was derived from sulphur.

I leave it to the adherents of phlogiston to accommodate these phænomena to their doctrine; considering it, for my own part, as superfluous to bestow any further attention upon a

system which, after a long discussion, has been fully refuted in all its modifications, and which indeed seems on the eve of being universally abandoned.

I have the honour to be, &c.

THOMAS BEDDOES.

